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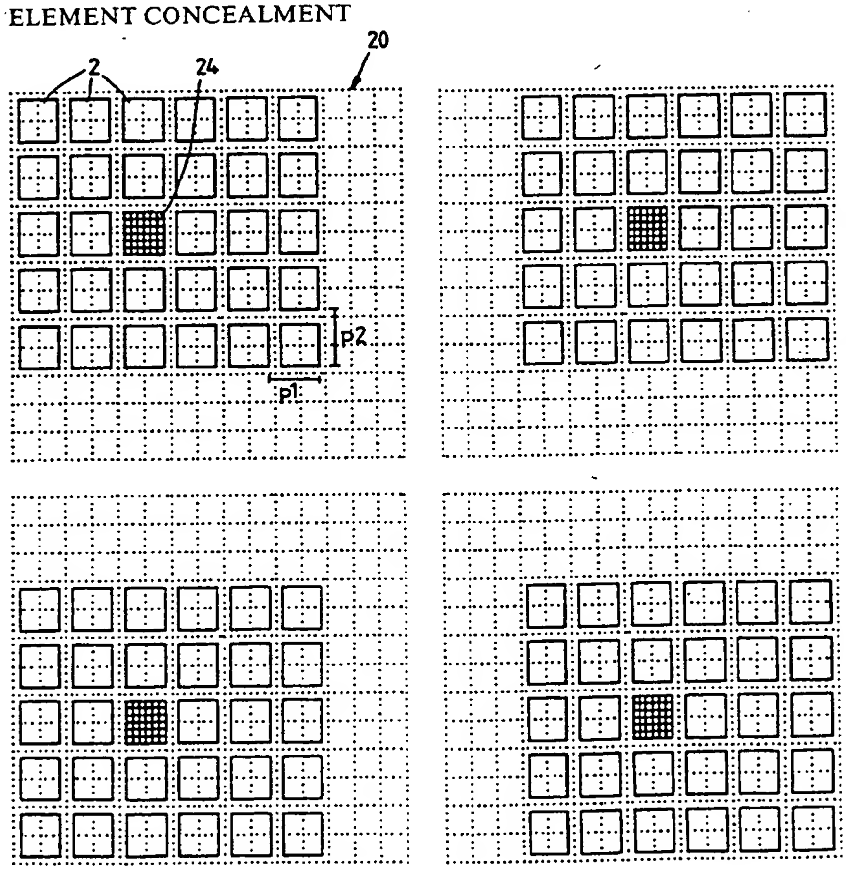
(54) Title: IMAGING SYSTEM WITH DEAD ELEMENT CONCEALMENT

(57) Abstract

A solid state imaging system with improved dead element concealment comprises image displacement means which cyclically displaces the image (20) relative to the array by a distance of at least one inter element pitch (P1, P2), in at least one coordinate direction of the array, so that each resolvable area of the image is focussed cyclically onto at least two different elements (2). By means of signal processing the output of each dead element (24) is replaced by output associated with the same area of the image but recorded by a different element in a previous image position.



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Imaging system with dead element concealment

This invention relates to imaging systems and particularly to solid state systems comprising an array of photoelectric elements, or staring array, for imaging electromagnetic radiation, generally in the visible or infra-red wavebands.

One such system comprises a two-dimensional array of charge coupled devices (CCD's). An image incident on the array causes each CCD to produce an electric potential dependent on the intensity of the image. The output from each CCD is recorded in turn and stored in a frame store for subsequent signal processing and storage or display.

The resolution of the system depends on the size and spacing of the photoelectric elements in the array and on the quality of each element. By applying conventional data sampling theory to the array it is appreciated that the highest spatial frequency which can be reproduced is equal to half the sampling frequency, which in this case is determined by the inter element pitch. If the image possesses spatial frequencies greater than half the pitch the displayed frequency will be a lower aliased frequency so that high frequency detail is obscured. There is a constant desire for improved spatial resolution, but the size and spacing of the elements in an array are limited by current manufacturing constraints.

In order to improve the resolution of such a system GB 2152781 proposes shifting the image relative to the array by a fraction, such as a half or a quarter, of the inter element pitch in either one or both of the coordinate directions of the array. This has the effect of reducing the pitch and hence the spatial frequency of the image which can be reproduced without aliasing.

The pixelated displayed image can be difficult to interpret and it is most usual for a system to include some signal processing operations which modify the image before display. These operations may include horizontal and vertical filtering and contrast averaging

for example to effectively blurr the edges of each display pixel. These types of operation may actually obscure high frequency detail but are considered necessary in order to enhance the acceptability of the displayed image to the viewer.

One such signal processing operation is the effective concealment of non-working or dead elements by averaging the outputs of neighbouring elements associated with neighbouring areas of image. This is generally necessary because present manufacturing constraints mean that 100% element operability is not achievable. In practice the most expensive arrays operating in the visible waveband may have less than 0.1% dead elements but arrays operating in the infra-red wavebands typically have between 0.1% and 5% dead elements. Averaging outputs from neighbouring elements clearly means that spatial resolution is reduced in the vicinity of a dead element and the effect is even worse in the event two neighbouring elements are dead. For certain applications the loss of resolution of fine detail resulting from a percentage of dead elements as low as 0.1% is not acceptable and much work has concentrated on increasing the reliability of manufactured photoelectric elements and improving dead element concealment signal processing techniques.

It is an object of the present invention to provide an imaging system having improved dead element concealment.

According to the present invention there is provided an imaging system comprising a two-dimensional array of photoelectric elements, focussing means for focussing an optical image on the array, signal processing means for processing the output taken from each element and image displacement means wherein the image displacement means is adapted to cyclically displace the image relative to the array in at least one coordinate direction of the array by a distance at least as great as the inter element pitch in that direction so that each resolvable area of the image is focussed cyclically onto at least two different elements and wherein the signal processing means is adapted to replace the output of each dead element by output associated with

the same area of the image but recorded in a previous image position by a different element.

The primary advantage of this method of dead element concealment is that an area of the image initially incident on a dead element will subsequently be incident on a different element, so that provided the second element is not also dead at least one actual output will be recorded in respect of each resolvable area of the image instead of relying on an average of the neighbouring outputs. Furthermore, every display pixel represents actual output associated with the corresponding area of image, even if the information came from a previous field, rather than averaged output associated with neighbouring areas of image. The effect on the display is that any area of image focussed onto a dead element during any part of the displacement cycle merely has an effectively reduced sampling rate as opposed to an estimated output.

A further practical advantage is that an array containing significant numbers of dead elements may now be useful in an imaging system, even where high resolution is required. The ability to use arrays with large numbers of dead elements dramatically increases the effective manufacturing yield and consequently significantly reduces the cost of a useful array.

The signal processing means may also perform certain conventional signal processing operations and it is also preferably adapted to displace the output from each element in opposed synchronisation with the image displacement so that each display pixel created corresponds to the area of the image from which the output was taken. The practical effect of this is to remove the image displacement from the displayed picture and thereby to reduce picture flicker.

The displacement means is preferably adapted to displace the image at least once in each coordinate direction of the array per cycle of displacement. This means that each resolvable area, away

from the edge of the image, will be incident on at least four different elements per cycle. In practice this means that the chance of getting less than two actual output readings for any resolvable area per cycle of four displacements is virtually zero.

The image is preferably displaced by one and a half times the inter element pitch. This allows the advantages of dead element concealment to be combined with the known advantages of displacement by a fraction of the inter element pitch, namely reducing the spatial frequency of the image which can be reproduced without aliasing.

The displacement means conveniently comprises an optical element, such as a reflective element provided in object space or a refractive element provided in image space, linked to a mechanical drive. The scan amplitude of the image relative to the array must be at least twice the size of that required by the prior art and consequently there is a risk that increased aberrations may be introduced. The advantage of using a reflective element in object space is that no image aberrations are produced and therefore the increased scan amplitude has no effect on the quality of the image. Spherical aberration introduced as a result of a refractive element in image space may be corrected for in the lens design and, in any case, is negligible if the thickness of the refractive element is kept to a minimum.

If the displacement is caused by periodically tilting the optical element through a given angle the slew rates of the mechanical displacements must be greater then in prior art systems and power consumption will also be greater. However, neither of these factors amounts to a problem in practice.

Alternatively, the displacement may be caused by rotating a refractive disc having areas of different thickness or of different refractive index, as illustrated in Figure 2 of GB2152781. In this case rotation is at the same rate as in the prior art system and so power consumption is not increased but the difference in thickness or

refractive index between the different parts of the disc must be greater to cause the required displacement and this may introduce image aberration.

The displacement of the image is synchronised with the fields of output taken from the array so that one field is read during each image position.

The dead element output replacement may be effected by incorporating a map of the dead elements in the array into the signal processing circuitry. Alternatively, the signal processing means may be adapted to recognise the presence of a dead element in real time.

The invention will now be described by way of example only with reference to the accompanying drawings, in which:-

Figure 1 schematically illustrates a first embodiment of an imaging system according to the present invention;

Figure 2 illustrates part of the system of Figure 1 in more detail;

Figure 3 illustrates a second embodiment of the part of the system shown in Figure 2;

Figure 4a and b illustrates a cycle of image displacement relative to an array according to the present invention; and

Figure 5a and b illustrates a cycle of image displacement relative to an array according to the prior art.

Referring to Figure 1 an image of an object (not shown) is brought into focus in the plane of a two-dimensional array 1 of photoelectric elements 2 by a lens 3. A refractive plate 4 is mounted in image space between the lens 3 and array 1 such that it can be tilted into four positions by means of mechanical drive 5. A signal

output from the array 1 is operated on by standard signal processing circuitry 6 in order to improve the acceptability of the pixelated display to the human eye. A previously calculated map 7 of the dead elements known to exist in the array 1 is fed into the dead element output replacement circuitry 8 which replaces the output of each dead element by output associated with the same area of the image but recorded in a previous image position by a different element. Further circuitry 9 then displaces the output in opposed synchronisation with the image displacement so that image displacement has no effect on the displayed picture 10.

The arrangement of the refractive plate 4 is shown in more detail in Figure 2. It is mounted generally parallel to the array 1 but can be tilted through an angle of β in order to cause an image displacement D relative to the array 1. The array 1 comprises rows of elements 2 in which the inter element pitch is p1 and columns of elements 2 in which the inter element pitch is p2. β can therefore be calculated for each coordinate direction so that displacement D is equal to one and a half times the inter element pitch, p1 or p2 as appropriate, using the equation:

$$D = t\,\beta\,\frac{(n-1)}{n}$$

where: t is the thickness of the refractive plate
n is the refractive index of the plate material.

In an alternative embodiment the refracting plate 4 is replaced by a mirror 11 in object space, as shown in Figure 3. The mirror is also mounted such that it can be tilted through an angle $\emptyset$ in order to cause image displacement D, relative to the array, equal to one and a half times the inter element pitch. In this case the equation required to calculate the necessary angle of tilt is:

$$D = 2\,f\,\emptyset$$

where: f is the focal length of the lens.

Figure 4a represents an optical image 20 incident on an array of photoelectric elements 2. The image 20 is displaced relative to the array by one and a half times the inter element pitch p1 or p2 in each coordinate direction of the array per displacement cycle, the Figure showing the four image positions relative to the array which make up a complete frame of information for display. The array includes one dead element 24. Figure 4b shows the resolution elements in the image (corresponding to display pixels in the displayed image), with the number of times each resolvable part of the image is sampled per cycle. It can be seen that every pixel away from the edge of the array is sampled at least three out of the possible four times per cycle. Even if a cluster of three dead elements occurs in the array each part of the image is sampled at least once per cycle.

In comparison Figure 5a represents an image 20 incident on an array of photoelectric elements 2 wherein the image 20 is displaced by half the inter element pitch p1 or p2 in each coordinate direction of the array, in accordance with the prior art. Again the array includes one dead element 24. Figure 5b shows that one resolvable part of the image is never sampled due to the presence of the dead element 24, and that consequently one display pixel receives no real information. Such a blank in the display is normally concealed by signal processing techniques. The advantage of the present invention is that every display pixel receives actual information relating to the corresponding part of the image rather than signal processed information relating to neighbouring parts of the image.

CLAIMS

1. An imaging system comprising a two-dimensional array (1) of photoelectric elements (2), focussing means (3) for focussing an optical image (20) on the array (1), signal processing means (6,7,8,9) for processing the output taken from each element and image displacement means (4,5,11) wherein the image displacement means is adapted to cyclically displace the image (20) relative to the array (1) in at least one coordinate direction of the array by a distance at least as great as the inter element pitch (p1,p2) in that direction so that each resolvable area of the image is focussed cyclically onto at least two different elements and wherein the signal processing means is adapted to replace the output of each dead element (24) by output associated with the same area of the image but recorded in a previous image position by a different element.

2. An imaging system as claimed in claim 1 wherein the signal processing means (9) is adapted to displace the output from each element in opposed synchronisation with the image displacement so that each display pixel created corresponds to the area of the image from which the output was taken.

3. An imaging system as claimed in claim 1 or claim 2 wherein the displacement means (4,5,11) is adapted to displace the image at least once in each coordinate direction of the array per cycle of displacement.

4. An imaging system as claimed in any preceding claim wherein the displacement means is adapted to displace the image by a distance equal to one and a half times the inter element pitch (p1,p2).

5. An imaging system as claimed in any preceding claim wherein the

displacement means comprises an optical element (4,11) linked to a mechanical drive (5).

6. An imaging system as claimed in claim 5 wherein the optical element is a reflective element (11) provided in object space.

7. An imaging system as claimed in claim 5 wherein the optical element is a refractive element (4) provided in image space.

8. An imaging system as claimed in any preceding claim wherein the signal processing means (7) incorporates a map of the dead elements in the array.

9. An imaging system as claimed in any of claims 1 to 7 wherein the signal processing means is adapted to recognise the presence of a dead element in real time.

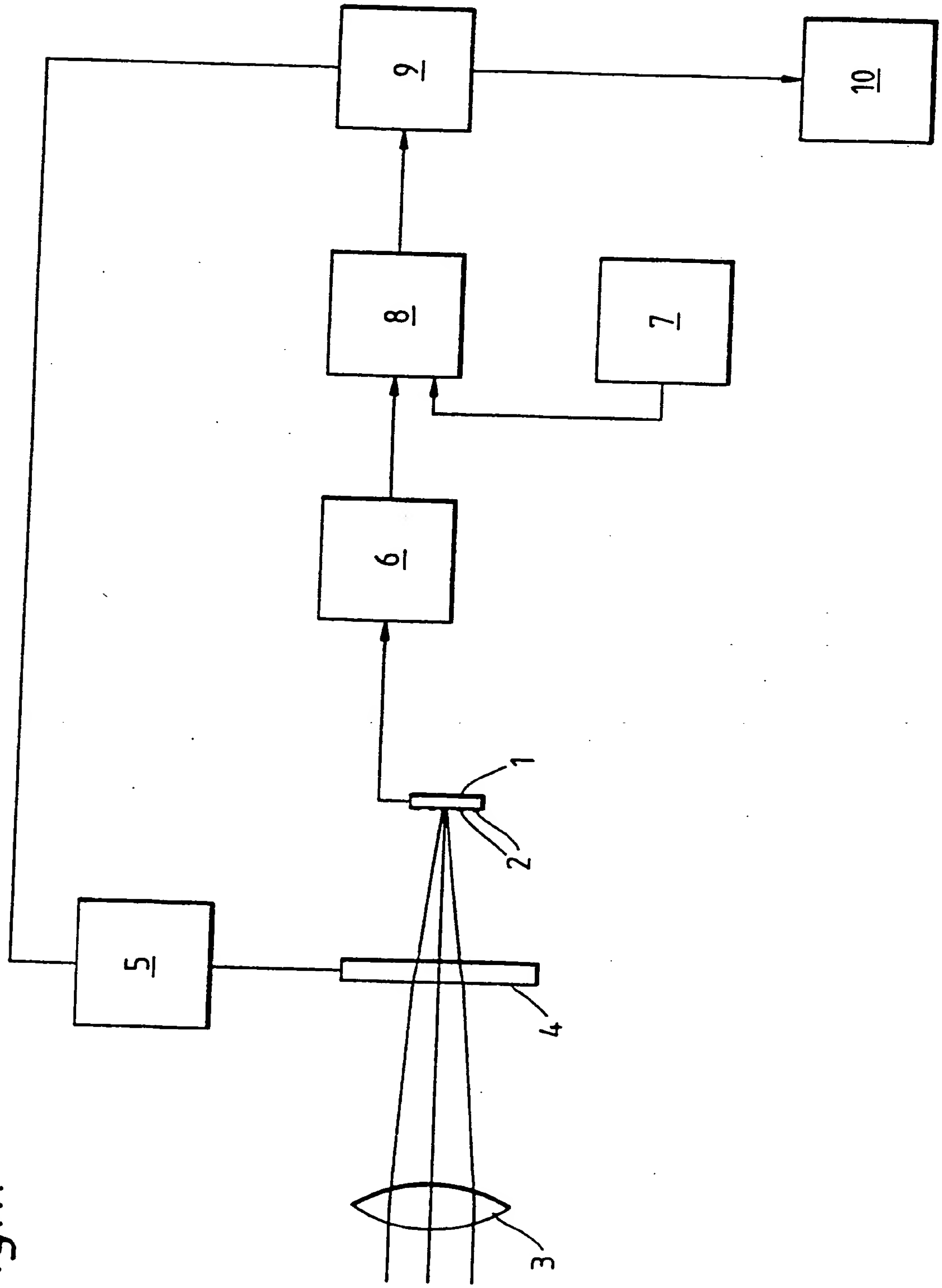

Fig.1.

Fig. 2.

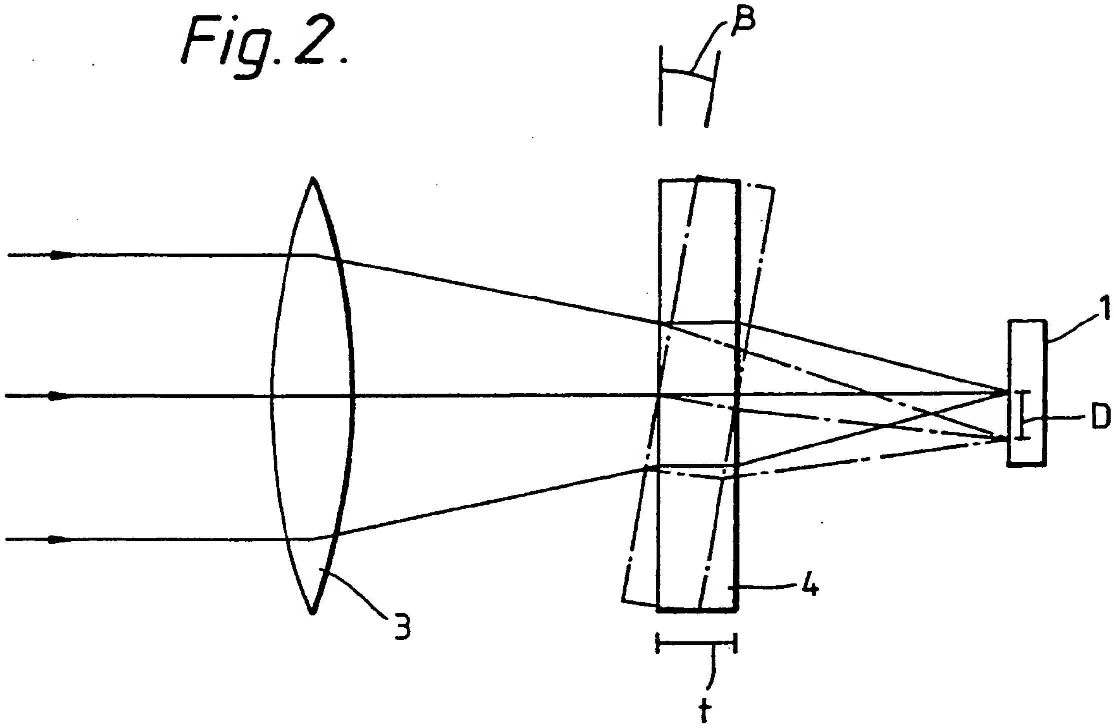

Fig. 3.

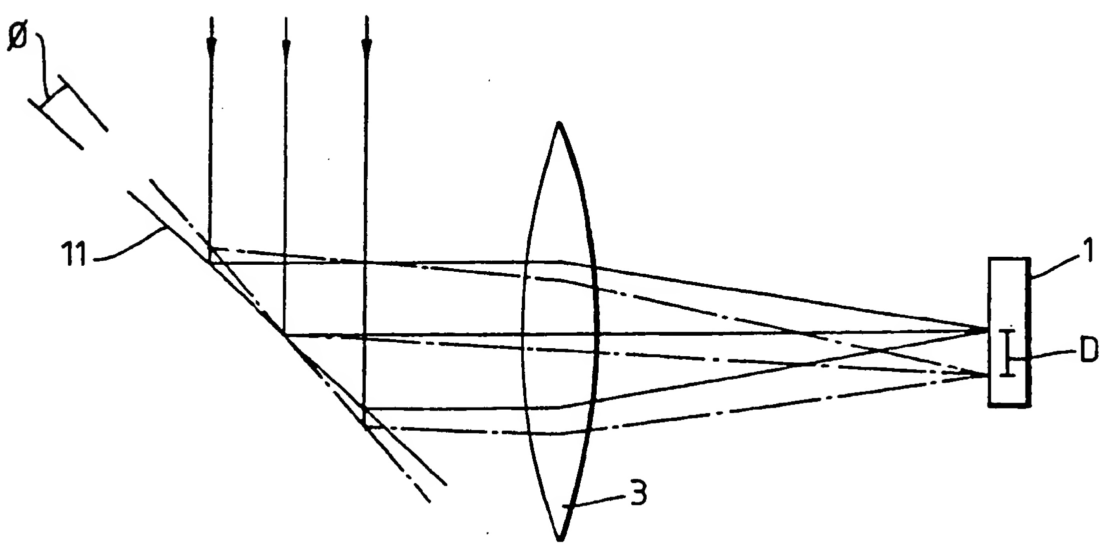

Fig.4a.

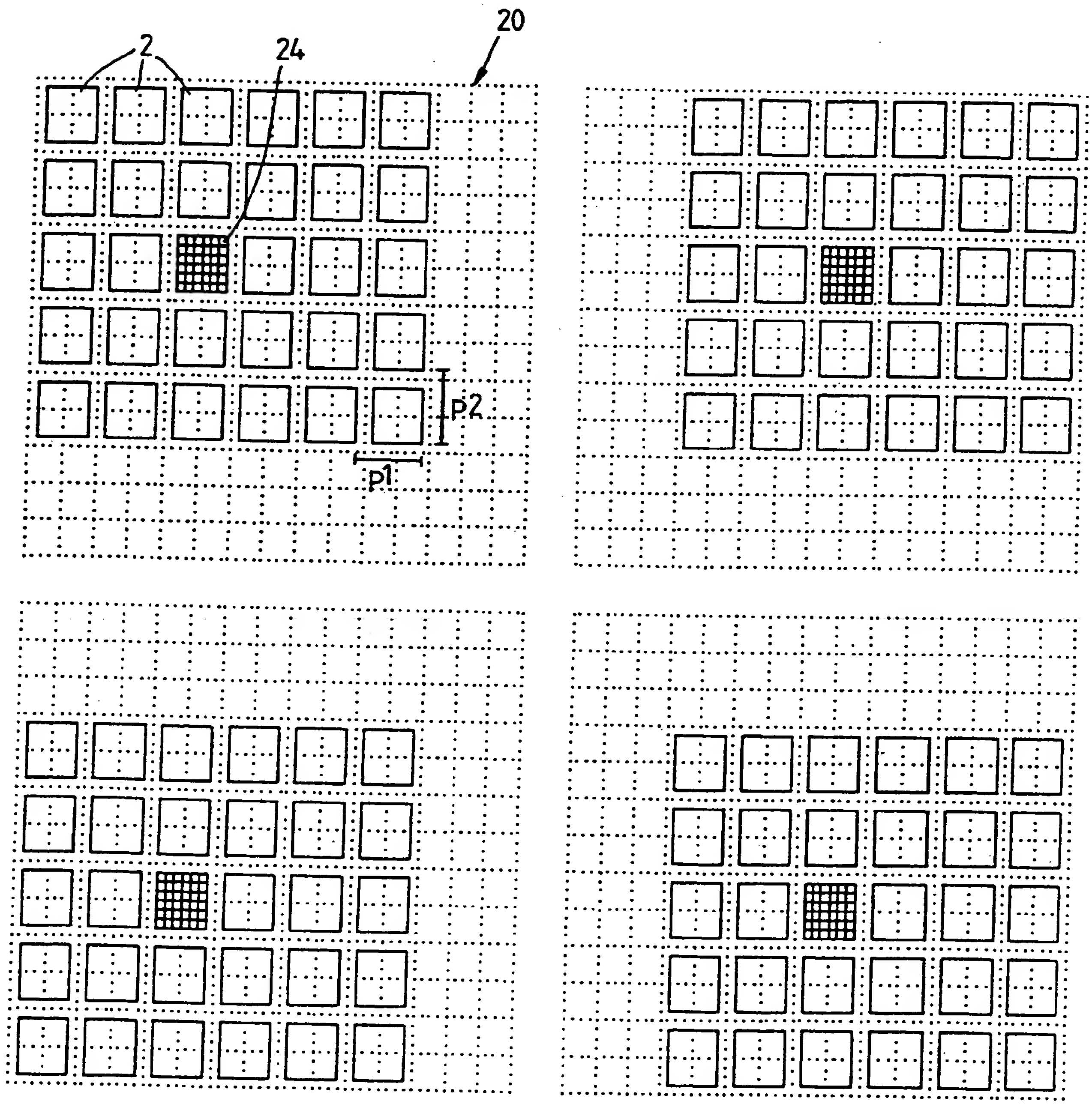

Fig.4b.

1	1	1	2	2	2	2	2	2	2	2	2	1	1	1
1	1	1	2	2	2	2	2	2	2	2	2	1	1	1
1	1	1	2	2	2	2	2	2	2	2	2	1	1	1
2	2	2	4	4	4	4	4	4	4	4	4	2	2	2
2	2	2	4	3	3	4	3	3	4	4	4	2	2	2
2	2	2	4	3	3	4	3	3	4	4	4	2	2	2
2	2	2	4	4	4	4	4	4	4	4	4	2	2	2
2	2	2	4	3	3	4	3	3	4	4	4	2	2	2
2	2	2	4	3	3	4	3	3	4	4	4	2	2	2
2	2	2	4	4	4	4	4	4	4	4	4	2	2	2
1	1	1	2	2	2	2	2	2	2	2	2	1	1	1
1	1	1	2	2	2	2	2	2	2	2	2	1	1	1
1	1	1	2	2	2	2	2	2	2	2	2	1	1	1

Fig.5b.

1	2	2	2	2	2	2	2	2	2	2	2	1
2	4	4	4	4	4	4	4	4	4	4	4	2
2	4	4	4	4	4	4	4	4	4	4	4	2
2	4	4	3	2	3	4	4	4	4	4	4	2
2	4	4	2	0	2	4	4	4	4	4	4	2
2	4	4	3	2	3	4	4	4	4	4	4	2
2	4	4	4	4	4	4	4	4	4	4	4	2
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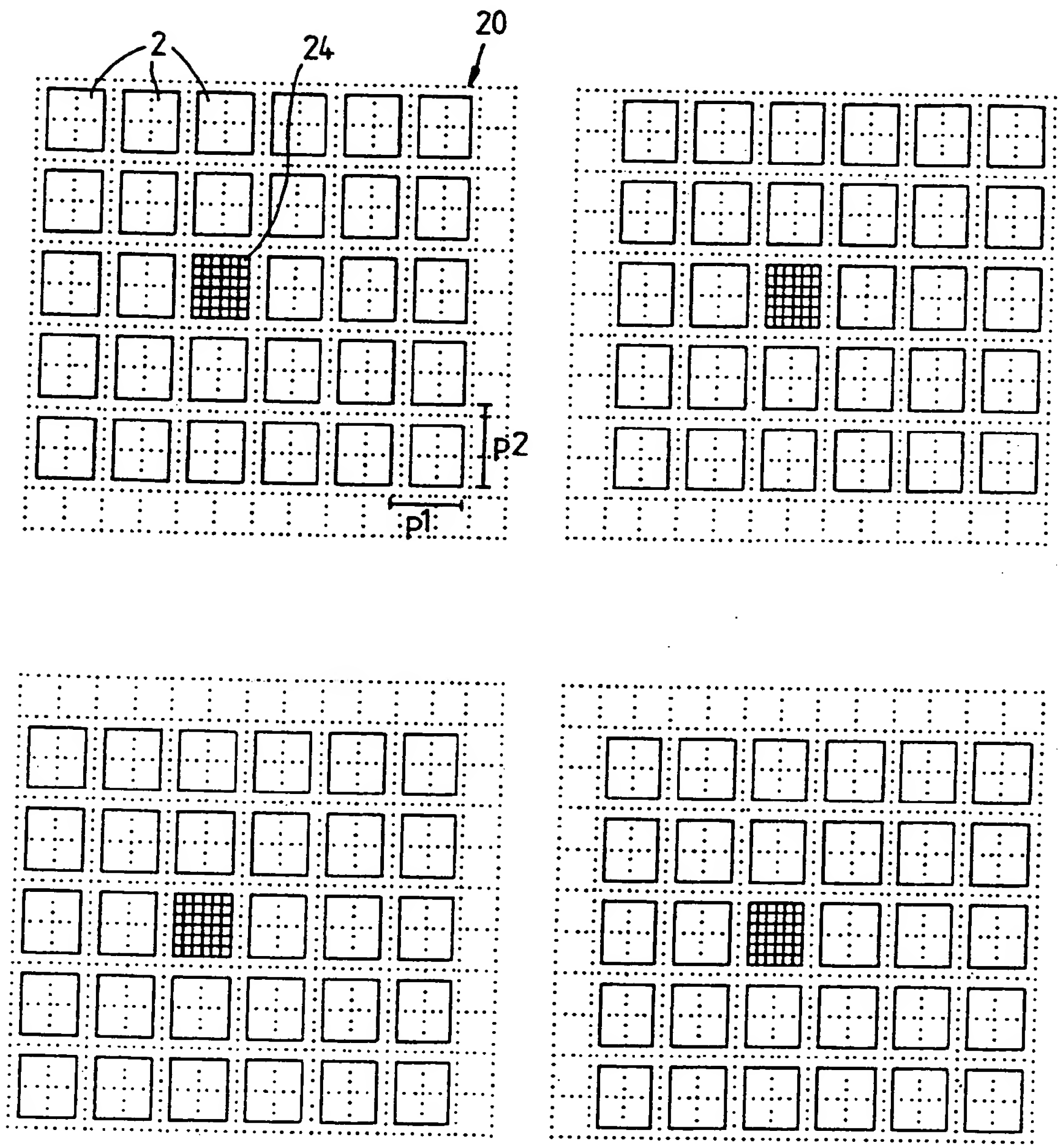
2	4	4	4	4	4	4	4	4	4	4	4	2
2	4	4	4	4	4	4	4	4	4	4	4	2
1	2	2	2	2	2	2	2	2	2	2	2	1

Fig.5a.



INTERNATIONAL SEARCH REPORT

International Application No PCT/GB 93/00896

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all)[6]

According to International Patent Classification (IPC) or to both National Classification and IPC

Int.Cl. 5 H04N5/217

II. FIELDS SEARCHED

Minimum Documentation Searched[7]

Classification System	Classification Symbols
Int.Cl. 5	H04N

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched[8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT[9]

Category °	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No.[13]
Y A	WO,A,8 802 971 (GURAL KENNETH) 21 April 1988 see page 4, line 16 - page 5, line 18 see page 7, line 19 - line 30 see page 16, line 14 - page 17, line 36 see figures 3A-3E	1-3,5-8 4
Y A	EP,A,0 483 530 (ELTRO GMBH GESELLSCHAFT FÜR STRAHLUNGSTECHNIK) 6 May 1992 see column 2, line 46 - line 58 see column 4, line 39 - line 50 see figure 3	1-3,5-8 4

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IV. CERTIFICATION

1

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
06 JULY 1993	21.07.93
International Searching Authority	**Signature of Authorized Officer**
EUROPEAN PATENT OFFICE	WENTZEL J.F.

III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)

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A	GB,A,2 140 649 (CITIZEN WATCH CO. LTD.,) 28 November 1984 see page 1, line 14 - line 35 see page 1, line 55 - line 113 see page 3, line 4 - line 18 see claim 12 ---	1-9
A	EP,A,0 131 387 (KABUSHIKI KAISHA TOSHIBA) 16 January 1985 see page 15, line 15 - page 16, line 24 see figures 10,A,10B ---	4
A	GB,A,2 241 401 (ROKE MANOR RESEARCH LIMITED) 28 August 1991 see page 1, line 5 - page 2, line 19 ---	9
A	PATENT ABSTRACTS OF JAPAN vol. 8, no. 155 (E-256)19 July 1984 & JP,A,59 056 768 (MITSUBISHI DENKI KK) 2 April 1984 see abstract -----	9

ANNEX TO THE INTERNATIONAL SEARCH REPORT ON INTERNATIONAL PATENT APPLICATION NO.

GB 9300896
SA 73469

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report.
The members are as contained in the European Patent Office EDP file on 06/07/93
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		JP-A- 59231981	26-12-84
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GB-A-2241401	28-08-91	None	

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